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Direct torque fuzzy control of PMSM based on SVM

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Abstract

In this article, we present the strategy of the direct Torque control (DTC) of the permanent magnets synchronous machine (PMSM) with fuzzy comparator in controlled by the technique SVM (Space Vector Modulation). This method of control allows reducing the fluctuations of the torque and of the flux also in the low speed contrary with control of the classical DTC where the frequency of switching is incontrollable. Simulations results obtained allow demonstrate the performances of this command especially in the behavior of the couple and the flux.

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Keywords: Permanent Magnet Synchronous Machine (PMSM), DTC, fuzzy,SVM, voltage inverter.

1. Introduction

DTC (Direct torque control) was proposed by TAKAHASHI Depenbrock and for the conduct of induction machines [1,2]. Subsequently many research works have been developed in this area [3,4,5] to improve the performance of this technique and compete vector control [6]. The current trend is to replace the asynchronous motor by the synchronous permanent magnet motor which is low cost and relative inertia torque much more important [7]. DTC control is based on a suitable choice of the carrier voltage applied by the inverter to develop the required torque. It has several advantages over conventional techniques [8,9]. Fast dynamic torque, robustness with respect to parameter variations, a control simple low-cost computing without Park transformation and control of torque independent of flow. In return, the switching frequency is variable and difficult to control due to the use of hysteresis controllers. To this end, high undulations appear on the torque and flux [10]. This has created a vast field of research and therefore, several studies have been developed to improve the harmonic distortion of the output waveform of the voltage inverter. They led to a significant change in the design of the control of the inverter. It is in this spirit that developed the sampled PWM technology, so that the control of the power converter is, too,

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synthesized digitally. As part this activity, and in order to control the switching frequency, we are interested to vector modulation, usually called SVM (Space Vector Modulation) with fuzzy controllers torque and flux. This method allows generating the voltage vector whose position and modulus are selected so as to drive the stator flux vector and the electromagnetic torque to their reference optimally [12, 13, 14].

2. Classic DTC

2.1- Modeling MSAP

the MSAP model without shocks, in reference Parck, shall consider the following simplifying assumptions: an unsaturated operating regime without losses and distribution of magnetic sine wave is defined by the following equations:

a- Electrical equations

$$\begin{aligned} V_d &= R_s I_d + \frac{d\varphi_d}{dt} - \omega\varphi_q \\ V_q &= R_s I_q + \frac{d\varphi_q}{dt} + \omega\varphi_d \end{aligned} \tag{1}$$

b- Flux equation

$$\begin{aligned} \phi_d &= L_d i_d + \varphi_r \\ \phi_q &= L_q i_q \end{aligned} \tag{2}$$

c- Equation of electromagnetic torque

$$C_{em} = p(L_d - L_q) I_d I_q + p\varphi_r I_q \tag{3}$$

d- mechanical Equation

$$j\frac{d\Omega_r}{dt} + f\Omega_r = C_{em} - C_r \tag{4}$$

2.2 Principle of DTC

The direct torque control of a permanent magnet synchronous machine is based on the appropriate selection of a voltage vector from a selection table to deliver the stator voltage vector. . In this selection, we use hysteresis comparators whose function is to monitor the status of the system, ie here the amplitude of the stator flux and electromagnetic torque [12,13]. The general structure of conventional DTC illustrated by the following figure:

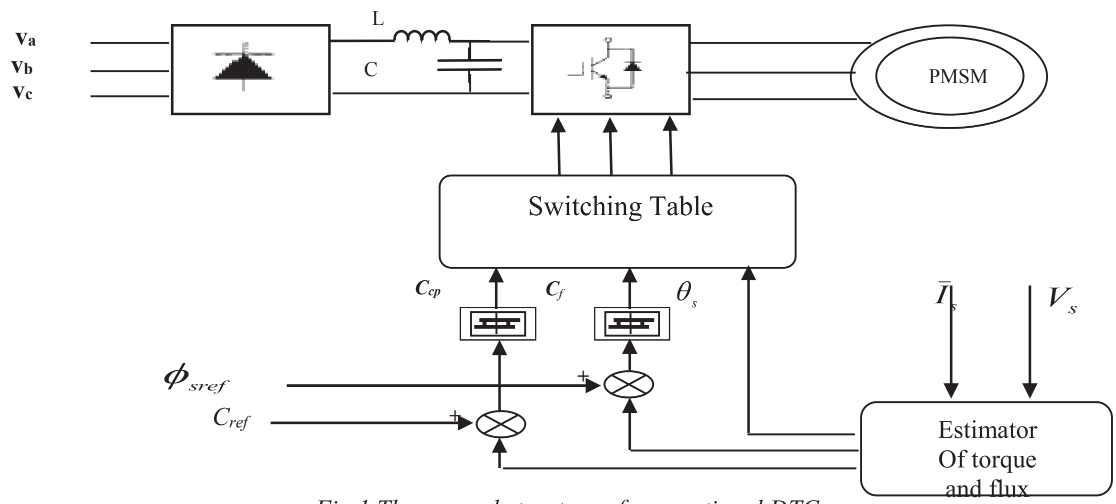


Fig.1 The general structure of conventional DTC

The supply voltage is supplied by a voltage inverter, that state switches, supposedly perfect, is represented by three Boolean control variables

$$V_s = \sqrt{\frac{2}{3}} U_0 \left[S_a + S_b e^{j2\pi/3} + S_c e^{j4\pi/3} \right] \tag{5}$$

Figure 2 represents the in the complex plane (α, β) the eight voltage vectors that can generate the inverter

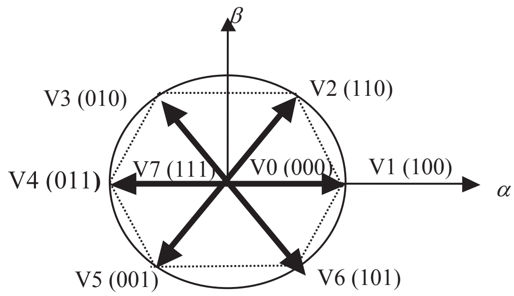


Fig.2 Voltage space vector

From the simplified model of the PMSM in a mark (α,β) connected to the stator, the stator flux is defined by the following equation:

$$\varphi_s(t) = \int_0^t (\overline{V}_s - R_s \bar{I}_s) dt \tag{6}$$

Assuming the voltage drop due to the negligible resistance against the stator voltage Vs are:

$$\varphi_s(t) \approx \varphi_{s0} + \int_0^t V_s dt \tag{7}$$

During a sampling period, the voltage vector applied to the machine remains constant, thus:

$$\Delta\varphi_s \approx V_s T_e \tag{8}$$

This relation shows that if the sampling period is fixed, Δφs is proportional to the voltage vector applied to the motor. In the case of the PMSM, the stator flux change even if one applies a zero voltage when the magnets rotate with the rotor. Therefore, the zero vectors are not used in the flow control/

b. Torque control

The electromagnetic torque can be estimated from the estimated values of the stream (φsα, φsβ) and current calculated quantities (is_{α}, $is_{\beta)}$

$$C_{em} = \frac{3}{2} p(\varphi_{s\alpha} i_{s\beta} - \varphi_{s\beta} i_{s\alpha}) \tag{9}$$

On the other hand, for the PMSM, the electromagnetic torque can be expressed as follows:

$$C_{em} = \frac{3}{2}\frac{P}{L_d}\phi_{S}.\phi_r.\sin\gamma \tag{10}$$

Where γ is the angle between the stator and rotor flux vectors. From this expression, if it remains constant stator flux can be controlled torque from the γ angle.

c. Selection of voltage vectors

When the flux vector is in a numbered box 'i', flow control and torque is provided by selecting one of the four non-zero or zero vectors of the two vectors [1, 2, 3, 4]. The role of the selected voltage vector is depicted in Figure3.

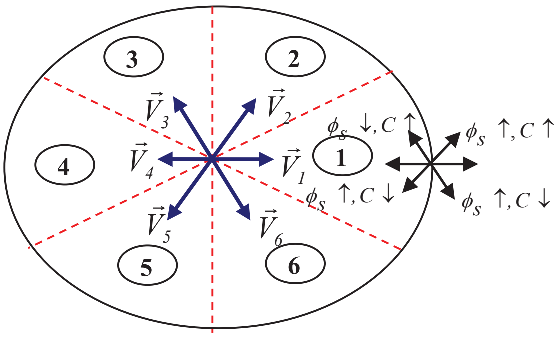


Fig.3 Selection of voltage vectors

It develops the table of the control structure as a function of the outputs of the hysteresis of the flow controller

Table 1: switching table for classical DTC

Torque	Flux	N=1	N=2	N=3	N=4	N=5	N=6
C_T=1	C_f=1	V_2	V_3	V_4	V_5	V_6	V_1
	C_f=0	V_3	V_4	V_5	V_6	V_1	V_2
C_T=0	C_f=1	V_6	V_1	V_2	V_3	V_4	V_5
	C_f=0	V_5	V_6	V_1	V_2	V_3	V_4

III. Principle of fuzzy direct torque control

The strategy of fuzzy direct torque control with PWM vector of a PMSM is presented in figure (4), this strategy is based on the replacement of the hysteresis comparator and switching table by two fuzzy controllers that generates the module and the voltage vector angle in order to bring the stator flux and the electromagnetic torque to references optimally, [11,12,14]. This vector is used by a PWM control vector to generate the pulses for the control of the switches of the inverter.

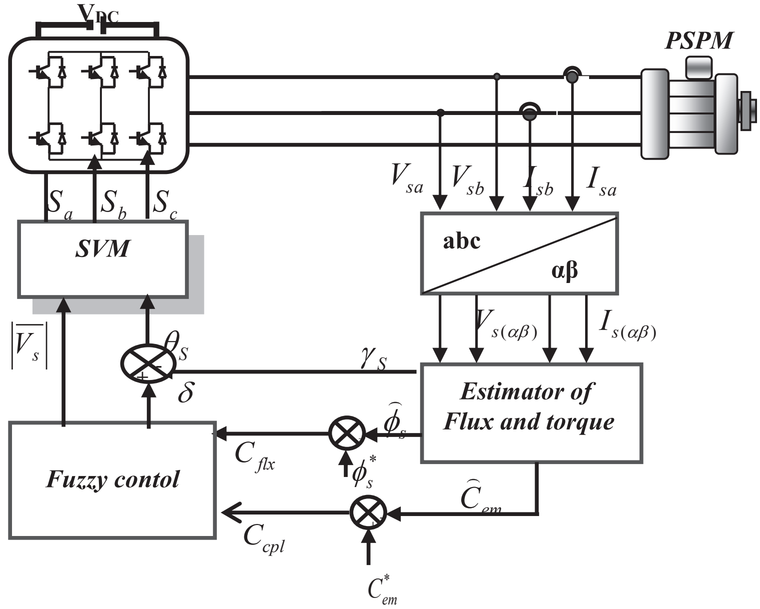


Fig.4 Control structure of DTC-fuzzy

3.1 Selecting the position of the voltage vector

The angle of the reference voltage vector relative to the stator flux vector should be selected so as to maintain the stator flux and the torque in a band in an optimum error band around their reference value. well-defined hysteresis. The errors of torque and flux are multiplied by "scales factors" to obtain standardized sizes and functions USING trapezoidal and triangular membership (fig. 5). These values are used by the fuzzification block to be transformed into fuzzy values. These are used by the block Sugeno type fuzzy control rules for the value to be added to the angle of the stator flux. Table 2 shows the table suggested for the selection of the angle δ

Table 2 : Increment angle of voltage vector

ε_{ϕ_s}	P			Z			N		
$\varepsilon_{C_{em}}$	P	Z	N	P	Z	N	P	Z	N
δ	$\frac{\pi}{4}$	0	$-\frac{\pi}{4}$	$\frac{\pi}{2}$	$\frac{\pi}{2}$	$-\frac{\pi}{2}$	$\frac{3\pi}{4}$	π	$-\frac{3\pi}{4}$

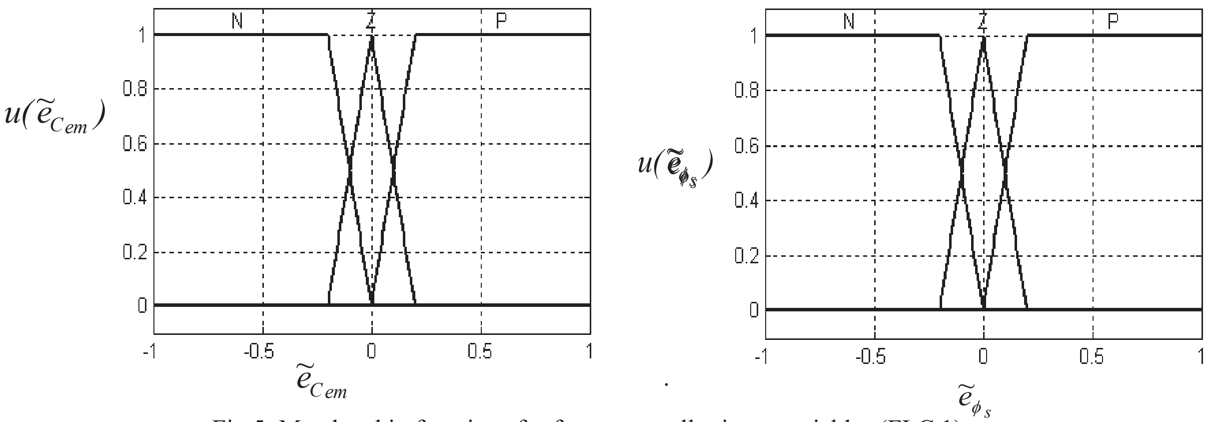


Fig 5: Membership functions for fuzzy controller input variables (FLC 1)

3.2 Selection of the voltage vector magnitude

The voltage vector module must be selected to minimize the error of torque and flux. A fuzzy logic controller is designed to generate the appropriate voltage vector magnitude (FLC 2), Figure 6 shows the membership functions for the input variables and outputs of the controller [11, 12, 13]

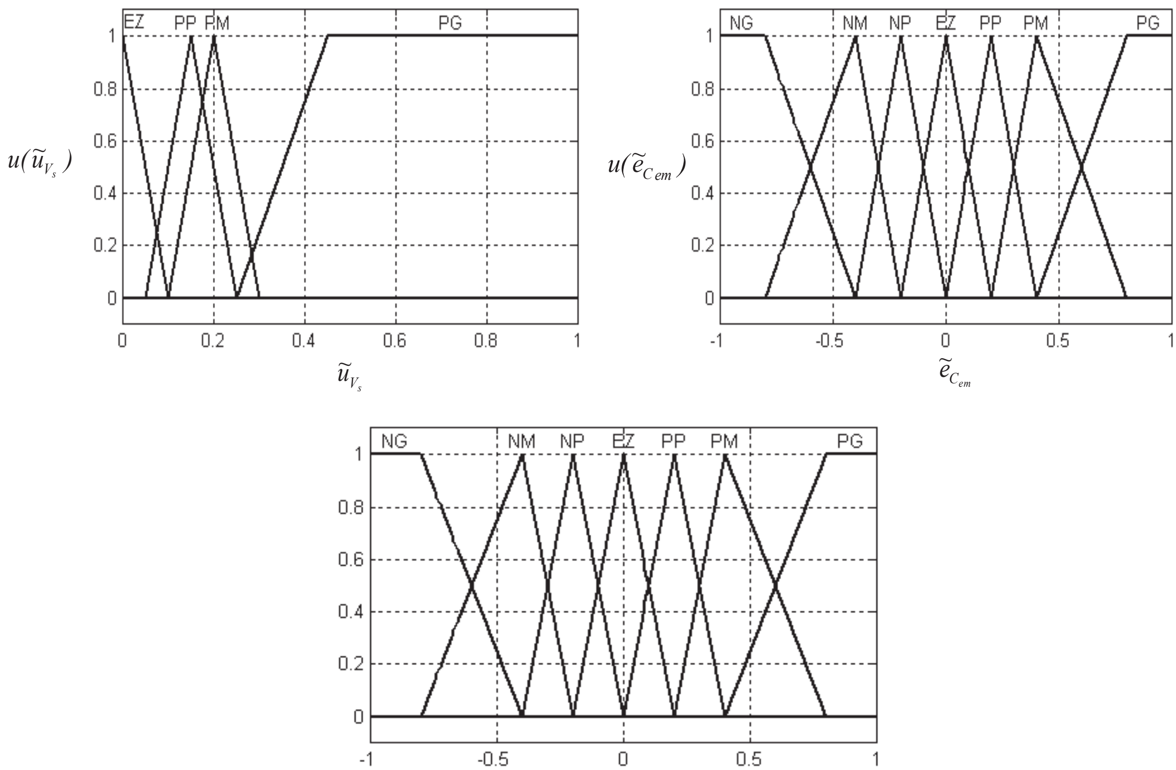


Fig .6 Membership functions for entree and output of the fuzzy controller (FLC 2)

$\tilde{e}_{\phi_s}$ \ $\tilde{e}_{C_{em}}$	NG	NM	NP	EZ	PP	PM	PG
NG	PG	PM	PP	PP	PP	PM	PG
NM	PG	PM	PP	PP	PP	PM	PG
NP	PG	PM	PP	EZ	PP	PM	PG
EZ	PG	PM	PP	EZ	PP	PM	PG
PP	PG	PM	PP	EZ	PP	PM	PG
PM	PG	PM	PP	PP	PP	PM	PG
PG	PG	PM	PP	PP	PP	PM	PG

Table 3: fuzzy decision rules

3.3 Generation States of the switches of the inverter

The voltage vector obtained from the characteristic comes to the vector modulation $\left|\overline{V_s}\right| = f(\varepsilon_{Cem})$ which in turn generates the states, and switches using V_α, V_β the following algorithm [10,11]:

a) Calculate the biphasic components of the desired voltage vector using the following equations:

$$\begin{cases} V_{s\alpha} = V_s \cos(\theta_s) \\ V_{s\beta} = V_s \sin(\theta_s) \end{cases} \tag{11}$$

b) Calculation of the area where the desired voltage vector is.

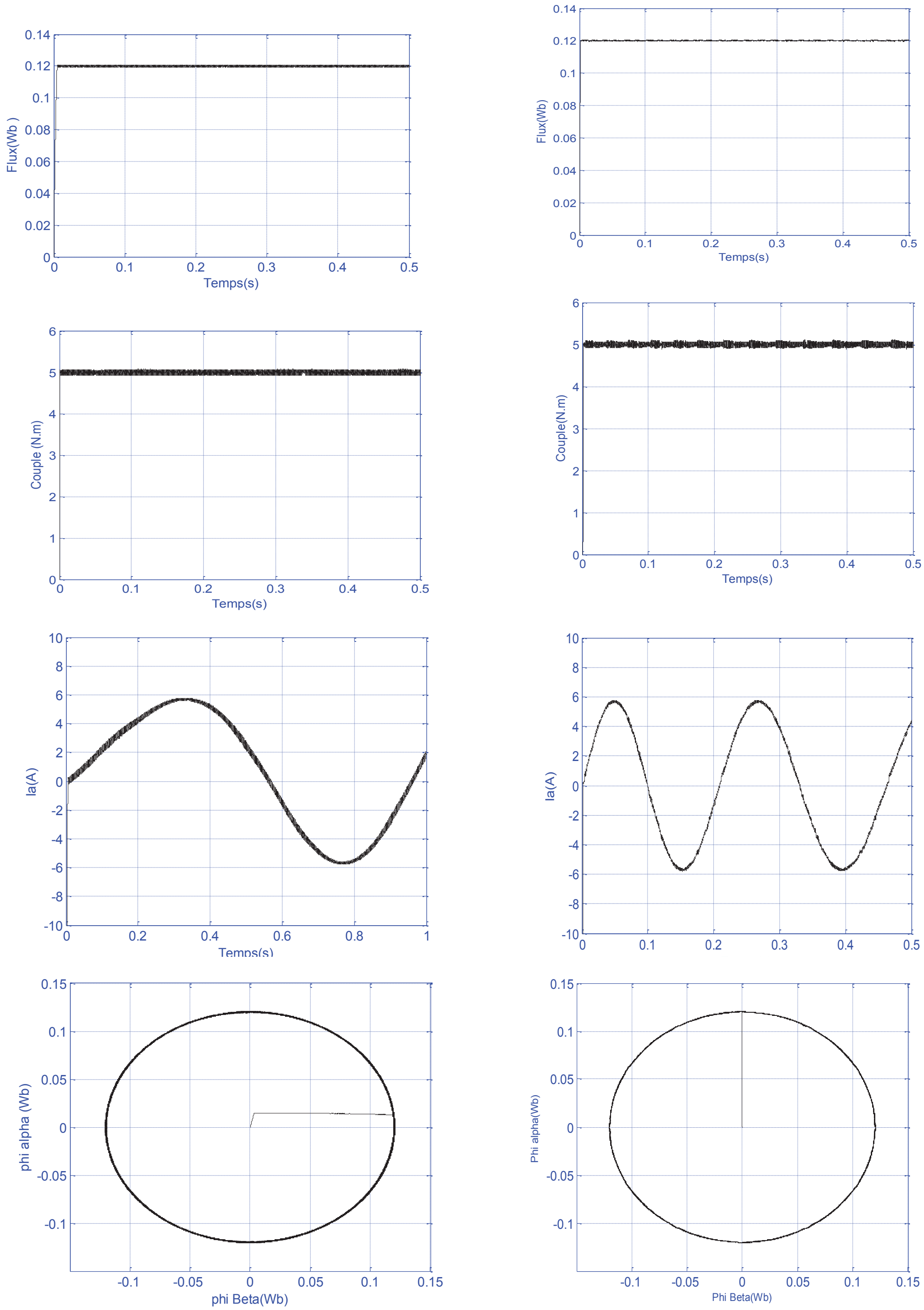
c) Get the switching vectors and their operating cycle and then .Calculer the operation of the zero vector switching cycle ($t_0 = 1 - t_1 - t_2$).

d) Calculation of the relative position of the clock (PRH) in the sampling time by using the following equations:

$$PRH = Rem(t/Ts)/Ts \tag{12}$$

Value PRH provides the components and the switching S_a S_b S_c vector according to the following routine:

- Otherwise,if $\mathrm{PRH} < \mathrm{t}_0/4 + \mathrm{t}_1/2$ then the swiching vectoris SV_1
- Otherwise,if $\mathrm{PRH} < \mathrm{t}_0/4 + (\mathrm{t}_1 + t_2)/2$ then the swiching vectoris SV_2
- Otherwise,if $\mathrm{PRH} < 3\mathrm{t}_0/4 + (\mathrm{t}_1 + t_2)/2$ then the swiching vectoris $V_7 = (1\ 1\ 1)$
- Otherwise,if $\mathrm{PRH} < 3\mathrm{t}_0/4 + \mathrm{t}_1/2 + t_2$ then the swiching vectoris SV_2
- Otherwise,if si $\mathrm{PRH} < 3\mathrm{t}_0/4 + \mathrm{t}_1 + t_2$ then the swiching vectoris



(a) *Classic DTC* (b) *DTCSVM-Fuzzy*

Fig. 7: Simulation results of the DTC control applied to PMSM

4. Results of simulation

Simulation results of the DTC control applied to PMSM are illustrated in figure 7 (a: DTC-classic, b: fuzzy DTC-SVM). This simulation was constructed using *Matlab m-files*,and *Simulink blocs*. We noticed a considerable reduction of torque ripples and flows. Less current distortion by using the Vector PWM .On the other hand, the fuzzy SVM-DTC shape has a constant switching frequency with a response time of torque and slower flow than conventional DTC.

5. Conclusion

In this article, we presented the strategy of direct torque control based on fuzzy vector PWM. This technique is characterized by a constant switching frequency reduces the switching losses in the inverter and harmonics reduced torque and flux.by analyzing the torque and flux wave forms, it shows those torque, and flux ripples can be reduced by the selected output voltage vector in one sampling period . The simulation results verify that the fuzzy SVM-DTC achieves a reduction of torque and flux ripples.

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